APPLICATION OF GEOMECHANICS IN IMPROVING BOREHOLE STABILITY DURING DRILLING

by

MUHAMMAD AKIF BIN ASRI

13655

Dissertation submitted in partial fulfillment
of the requirements for the
Degree of Study Bachelor of Engineering (Hons)
(Petoleum Engineering)

May 2014

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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD AKIF BIN ASRI

ABSTRACT

The borehole instability problem is undesirable problem whether before start drilling, during drilling or after drilling. The main problem related to borehole instability is stuck pipe problem. This stuck pipe problem is undesirable during drilling which can cause in non productive time (NPT). The stuck pipe problem could lead in sidetracking, equipment left in hole and also sometime hole collapse. The stuck pipe problem normally occurred in horizontal well or high angle well. The geomechanics study been already enters in petroleum industry to help in encounter the borehole stability problem. To encounter the stuck pipe problem, the borehole stability is needed which means geomechanics could help mitigate the stuck pipe problem.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Beneficent, the Most Merciful, I would like to express my gratitude to all person which contributes great experience and learning opportunities in working on my Final Year Project. I would like to express my deeply sincere gratitude and thank to my supervisor Dr. Syahrir Ridha for aiding me through this whole project with excellent support. Lastly, I also would like to thank my family member and friends for assisting me technically or mentally when I am working on this project. A warmth gratitude for everyone and may all the goodness and memories blessed by Allah.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: PROJECT BACKGROUND

1.1 BACKGROUND STUDY

Geomechanics, which includes all thermohydromechanical phenomena, this plays an important role in every operation involved in the exploitation of hydrocarbon in specifically is while drilling. Pressure change in the reservoir modifies the in situ stresses and cause strains not only to the reservoir but also to the entire sedimentary column. In return, these stress modifications and strains will change the stability parameters of the walls of the wells that to be drilled and flow properties of the fluid.

This project will be deals with the role of geomechanics in the optimization of drilling which is the borehole stability during drilling. Borehole stabilities can encounter at any stage in the life of a well and they are the main cause of drilling difficulties, resulting in substantial expenditures, substantial in non-productive times (NPT), sometimes even in the loss of part of even whole boreholes. Therefore, when a well is drilled, the rock surrounding the borehole must take up the load previously supported by the rock that has been removed. This will results in the development of a stress concentration at the borehole wall. If rock is not strong enough, the wall will fail.

1.2 PROBLEM STATEMENT

Borehole instability (BHS) during drilling is a common problem due some reasons in oil and gas industry. Over last two decades, engineering tools and knowledge for overcome borehole instability (BHS) problems already been significantly improved. Unfortunately, the understanding of borehole stability concept with regards to geomechanical is not yet explored.

Most of the cases in field revealed that the failure of borehole stability incidents mainly occurred in horizontal wells. When a well drilled at an oblique angle to laminations, it is exposed to planes of weakness causing severe instabilities. The high angles drilling in horizontal well will also leading to stuck pipe incident in the build up rate (BUR) section.

1.3 OBJECTIVES

The objectives of the project are:

- To study the application of geomechanics technology in improving borehole stability during drilling.
- To study how geomechanics avoiding stuck pipe incidents due to severe borehole instability in build up rate section.

1.4 SCOPE OF STUDY

The project starts by studying and revising the fundamentals of Geomechanics from any trusted sources such as published articles, journals, books and conference papers. By doing that, deeper understanding can be gained and comparison of theory and practical studies can be made.

The study also continued by learning how some borehole instability happened during drilling. Borehole stability is known as a balance between strength of rock formation and near wellbore pressure. The resulting imbalance that leads to wellbore failure occurs if the formation strength is less than the near wellbore stress. There are several factors that could affect both the formation strength and the near wellbore stresses, as for example; drilling fluid, drilling operation, temperature, and etc.

Therefore, in order to overcome borehole instability problems for some drilling project, the most important parameter are the rock formation and some mechanical properties, the planned wellbore trajectory, and subsurface in-situ stresses. Typically, geomechanics and borehole stability (BHS) involves drilling operation which by go through a offset well, compiling subsurface data such as estimation and measurement of formation rock properties and in-situ stresses and pore pressure,.

CHAPTER 2: LITERATURE REVIEW

2.1 BOREHOLE INSTABILITY

There are 4 types of borehole instability that are hole closure, hole enlargement, fracturing and collapse. The root causes of borehole instability may be grouped into a few section such as; Erosion caused by fluid circulation, Mechanical failure caused by in-situ stresses, and Chemical caused by interaction of borehole fluid with the formation.

Borehole instability principle stated that the strength of the rock at certain depth must be equilibrium with in-situ rock stresses that effective overburden stress and effective horizontal confining stresses. Although the hole is drilled, the balance between rock strength and in-situ stress can be interrupted which can cause hole instability problems.

Total avoiding of borehole instability cannot be done because of restoring the physical and chemical in-situ phases of the rock are almost impossible. Somehow, the drilling engineer can reduce borehole instabilities problem by adapting the good practices in field.

2.2 DETERMINATION OF IN SITU STRESSES

Some components can be estimated by observing the strain processes associated with the action of stresses on the material considered. In the absence of tectonic effects, the major principal stress is assumed to be vertical stress due to the weight of the overburden. The two other principal stress are horizontal and equal to Kvertical stress. According to the theory of elasticity, if we assume that there is no horizontal strain during burial and that the medium is isotropic and homogeneous, then we obtain:

$\sigma'_H = \frac{v_d}{1 - v_d} \sigma'_v$, where σ' are effective stresses and v_d the drained Poisson's ratio.

There are two method can be used to determined the in situ horizontal stress direction in vertical boreholes, which the first is based on analysis of borehole breakouts. Breakouts form at different depths when the concentration of compressive stresses exceeds the rock strength. The axis defined by breakout corresponds to the minimum horizontal stress azimuth. The second method is by using the traces of drilling-induced hydraulic fracture. Their azimuth is reliable indicator of the maximum horizontal stress directions.

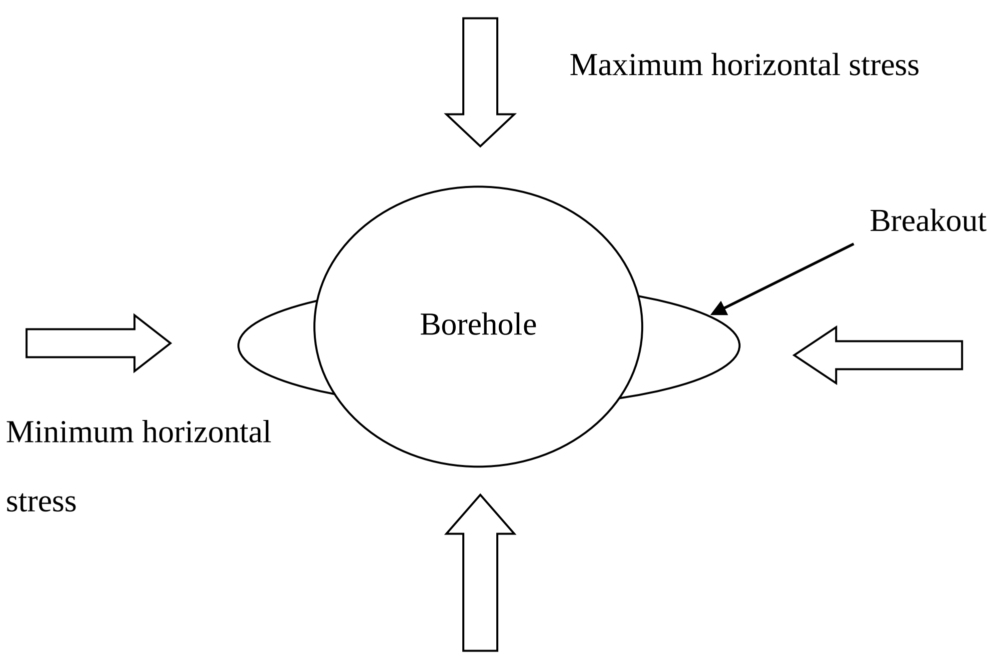

Figure 2.1. Breakouts and fractures induced in the stress field

2.3 BOREHOLE INSTABILITY IN HORIZONTAL WELL

Drilling data has been examined which by analyzed sixty wells from field. There were nine vertical, fifteen directional and the rest are horizontal wells. Data on instability instances from daily drilling report (DDR's) has been compiled which show that tight-holes represent the majority of instability instances (65%), followed distantly by stuck pipe (13%) and loss circulation (8%). 80% of these problems happened during hole control. Normally hole control problems will occur before or during the placement of casing, that why they are time delayed. **Figure 2.2** illustrated the occurrence of borehole instability problem [6].

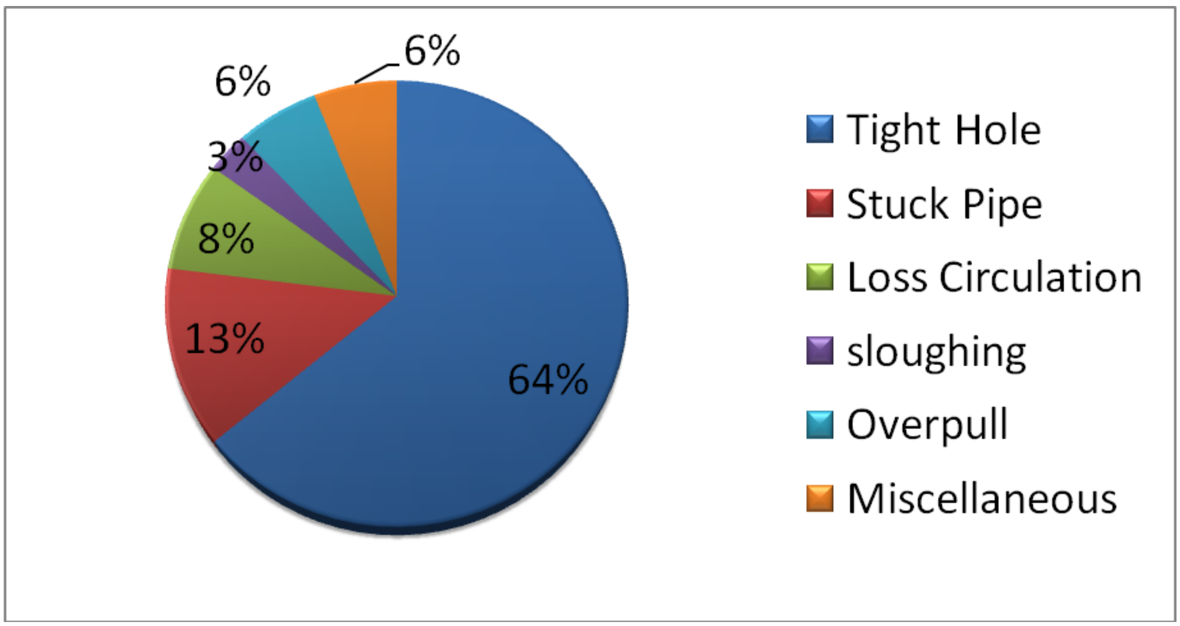

Figure 2.2. Occurrence of borehole instability problem [6].

Less than that, It is important to mention that pipe stuck issues is related to the problems of borehole instability. Drilling shale formation is the most troublesome cases. In common formation types, a too light in weight mud usage will lead to the collapse of the hole, which indirectly cause stuck in mechanical pipe. These causes usually indentify when there are suddenly rise in circulating drill pipe pressure, torque increasing, and in some issue no fluid return to the surface.

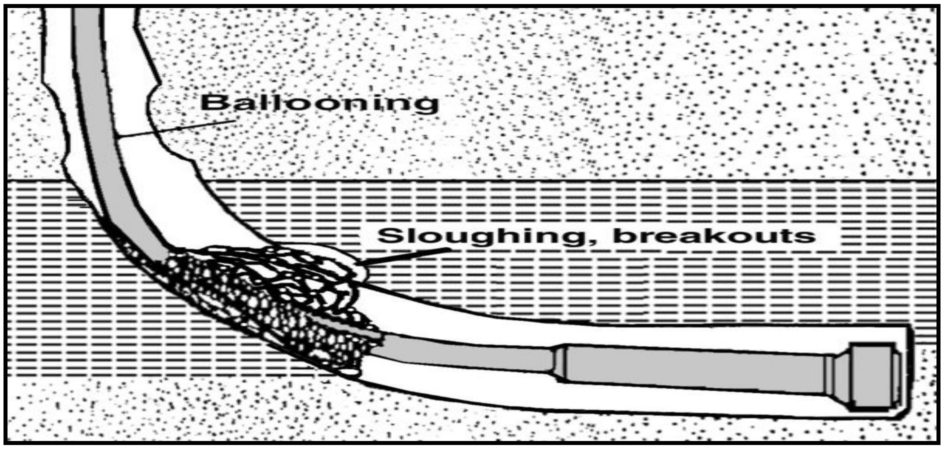

Figure 2.3. Pipe stuck caused by borehole instability

2.4 APPLICATION OF GEOMECHANICS IN BOREHOLE STABILITY

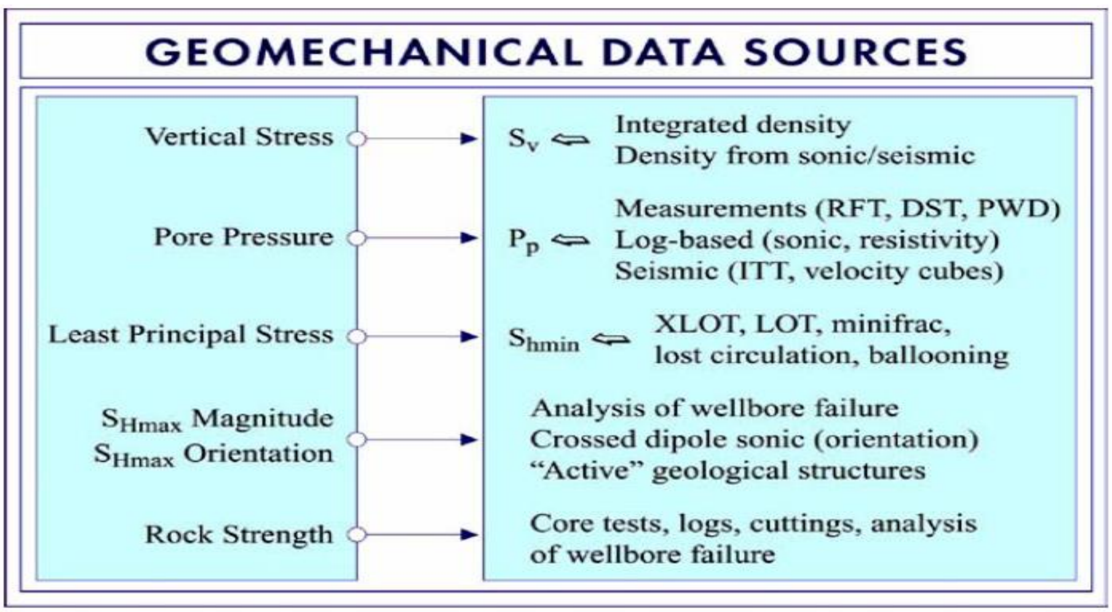

Figure 2.4. Core model components are essential to responsible geomechanical modeling [8].

Geomechanical modeling responsibility begins with the core. These components ultimately lead to guidance regarding mud weights required to prevent borehole failure. Furthermore, before using any of the models to predict the mud weight required to prevent wellbore failure, lack of failure, the offset wells where the failure actually occurs or does not occur [8].

Borehole instability highly counters on the state of stress around the borehole. The three principal stresses are vertical stress (S_v), maximum horizontal stress (S_{Hmax}), and minimum horizontal stress (S_{Hmin}). The relative magnitudes of the three principal stresses that can be used to measure the type of faulting stress regimes.

In terms of geomechanical, borehole failure is defined that borehole breakouts which some area in borehole wall caving that are due to stress concentrations near the wall itself that will make the outcome in shear failure. The breakout width is depends on the stress condition, drilling fluid pressure, and rock properties. If the breakout width is exceeds approximately 90 degree to 100 degree, it is likely will make the rest of the borehole wall will be collapse [8].

After a geomechanical model was develop, a different casing and weight plans should be tested against the safe operating mud window this is to ensure the new mud weight plans will not affect the borehole stability. The determination on how much borehole azimuth and inclination affect the operating of the mud weight window should be made to ensure the new plan mud weight is in line with inclination of borehole. There is also a way to check the sensitivity of wellbore failure with little change in mud weight. The selected casing plan must be analyses to identify the drilling risk due to uncertainties.

2.5 CASE STUDY

The case study on Guan Jia Pu Oil which located at Bohai Bay, China. This field encountered severe stuck pipe problem during a short period which lead to hole collapse and sidetracking.

Figure 2.5 shows the weight of the drilling fluid used in the formation of Sa Jie He. This figure also described how that the mud weight used in relation to the azimuth of well and borehole instability has no definite trend [10].

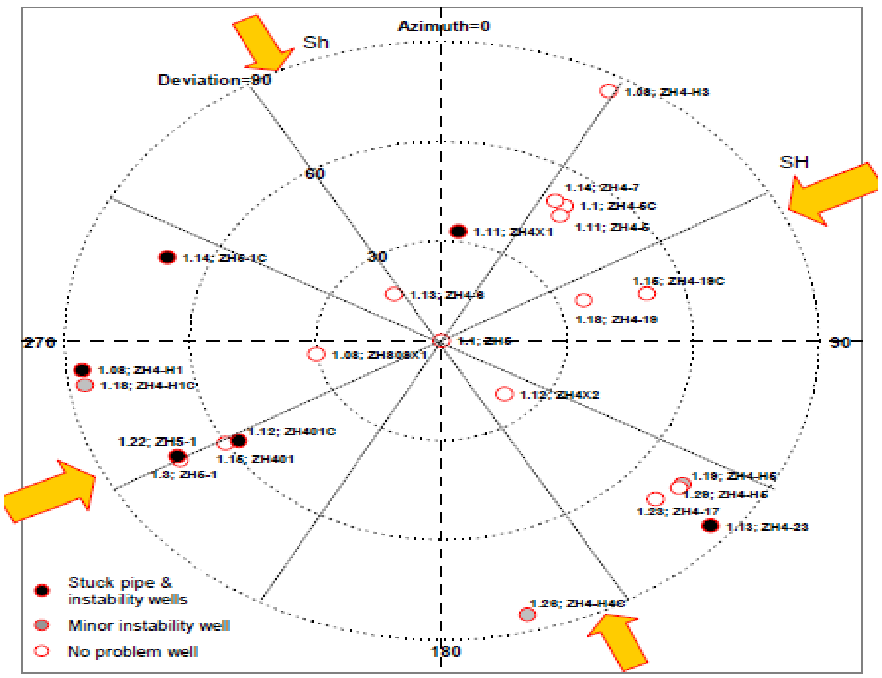

Figure 2.5. Effect of well azimuth on wellbore stability [10].

The effect on the stability of the wellbore deviation from **Figure 2.6**, which shows the relationship between the mud weight used and also well deviation in the formation of Sa He Jie.

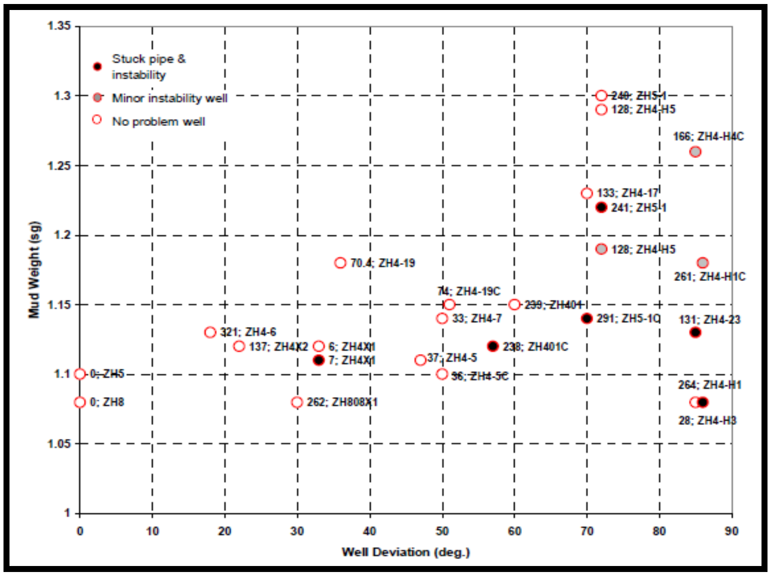

Figure 2.6. Effect of well deviation on wellbore stability

This is of well, an increase in mud weight of high-angle ZH4-23 also required. A mud weight that is further supported by **Figure 2.7**, which shows the relationship between the deviation of the well and the mud weight for three wells near that have same azimuth. With an increase in the deviation lower than the desired result in the collapse of the hole and stuck pipe in ZH4-23 [10].

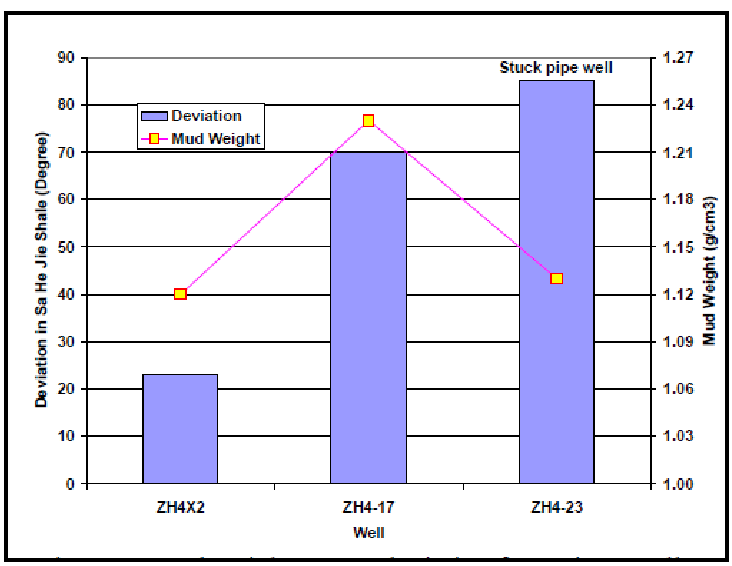

Figure 2.7. Mud Weight versus deviation for a given well azimuth [10].

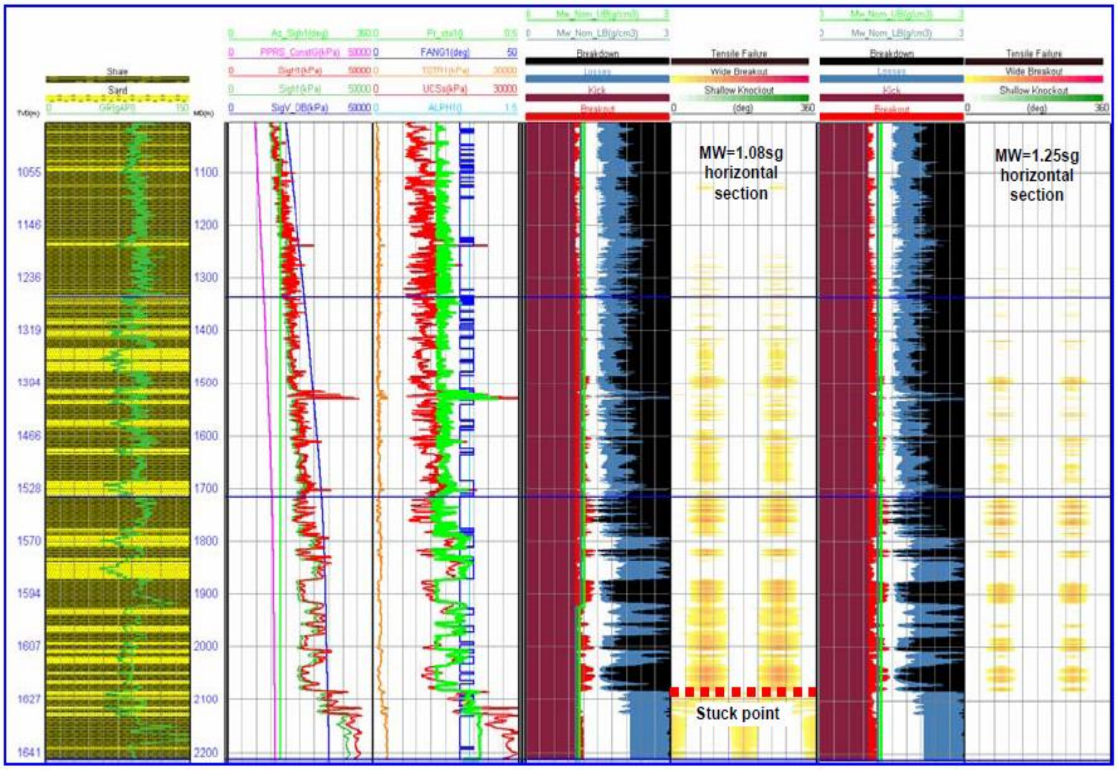

Figure 2.8. MEM and wellbore stability analyses for stuck pipe well [10].

Figure 2.8 above shows that wellbore stability analysis for a stuck pipe horizontal well, the Track 1-3 shows the MEM, mud weight window at Track 4 and Track 5 shows the calculated synthetic rock failure image on borehole surface, the Track 6 shows the new mud weight required to prevent the stuck pipe incident. This well was drilled along major horizontal stress direction. The first stuck point is encountered at 2103mMD. At 2118mMD, top drive stalled and pump pressure fluctuated between 11 MPa and 19MPa which lead to drill pipe is stuck completely.

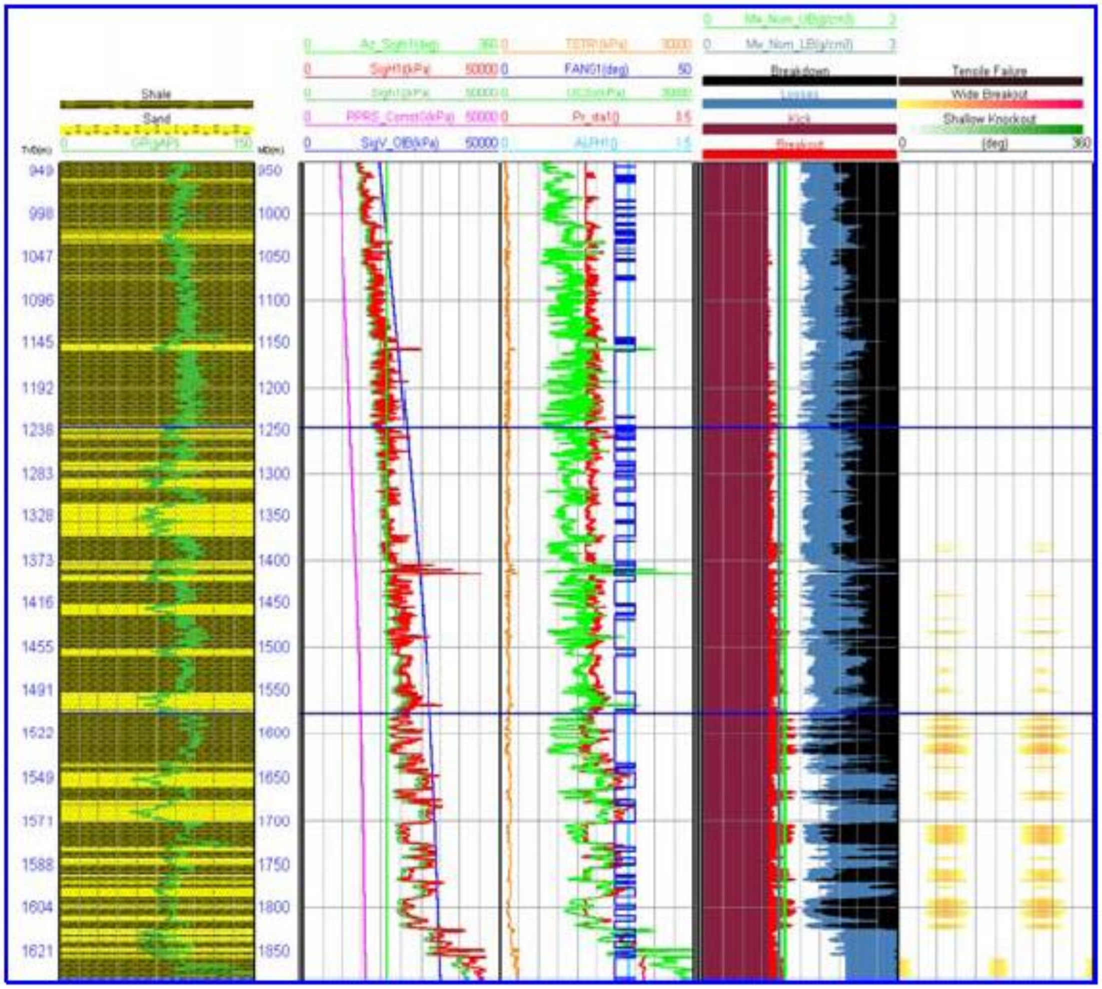

Figure 2.9. MEM and wellbore stability analyses for non-stuck pipe well [10].

To further investigate the relationship of mud weight in overcome borehole collapsed regards to stuck pipe, analyses were conducted in horizontal non-stuck pipe hole. This both wells had the same azimuth and inclination. Somehow the only different between this both well are that stuck pipe well almost 30m deeper than non-stuck pipe well. The main reason of no serious stuck pipe incidents are the relatively high mud weigh and good hole cleaning during reaming operations.

The next case studies in on horizontal well which located on gulf of Mexico. The first leg was drilled on 12,392 ft measured depth with 2172 ft lateral 90 degree or 345 degree azimuth. This first leg consumed time of 27 days. The first leg encountered severe borehole stability problem that resulted in stuck pipe incident. The first leg is drilled based on offset well without a particular borehole stability study or by using geomechanics.

The second leg was drilled on 13,790 ft measure depth with a 3570ft lateral 89 degree or 313 degree azimuth. This second leg consumed time of only 8 days compared to the first leg. The second leg was drilled immediately after drilling the first leg by using recommended mud weight or after the borehole stability study is initiated. This result result the second leg is trouble free during drilling.

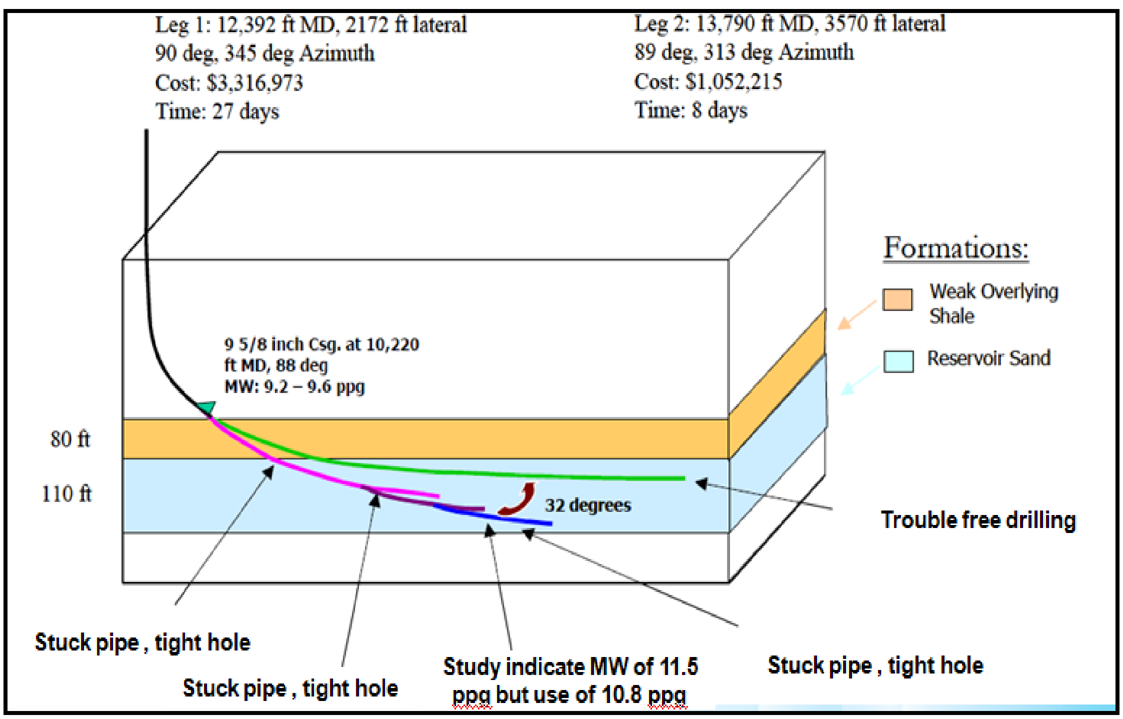

Figure 2.10. Schematic of case study gulf of Mexico with horizontal well.

The third case studies in on horizontal well which located on gulf of Mexico. A previously drilled production Mexico sub-salt structure was planned to be sidetracked to access another part of a reservoir around 6 400 meters (21 000 ft) true vertical depth (TVD).

The drilling history especially BHS related drilling troubles of the main hole and two other offset wells were well trouble plot on the **Figure 2.11** below which indicated the numerous occurrences of tight hole or stuck pipe problems below 55.88 cm (22 in.) casing shoe and problems continue into the deeper hole sections.

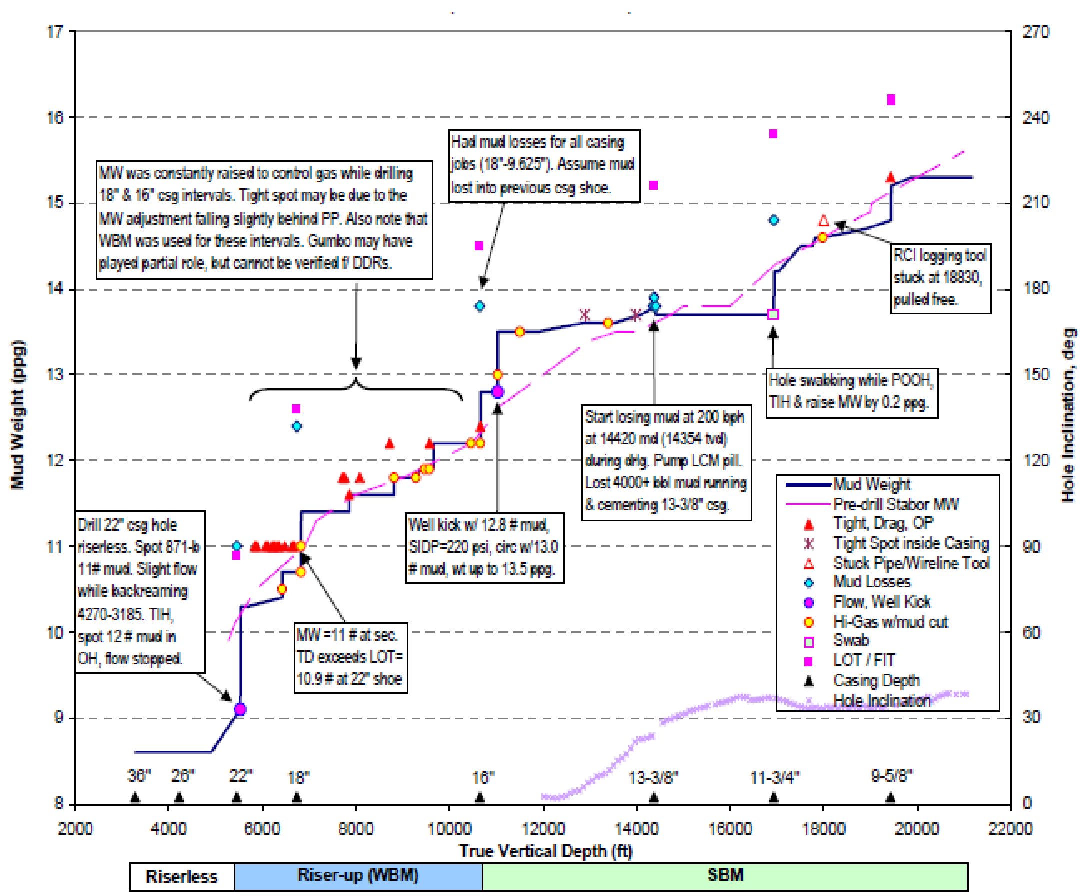

Figure 2.11. Overview of case study gulf of Mexico with horizontal well.

CHAPTER 3: METHODOLOGY

3.1 PROJECT FLOW

A specific approach of executing is required in this project like any other software hardware integrated project. This approach emphasizes on step-by-step development by finishing one step before advancing to the other until it reaches the final stages. **Figure 3.1** shows the project flow chart.

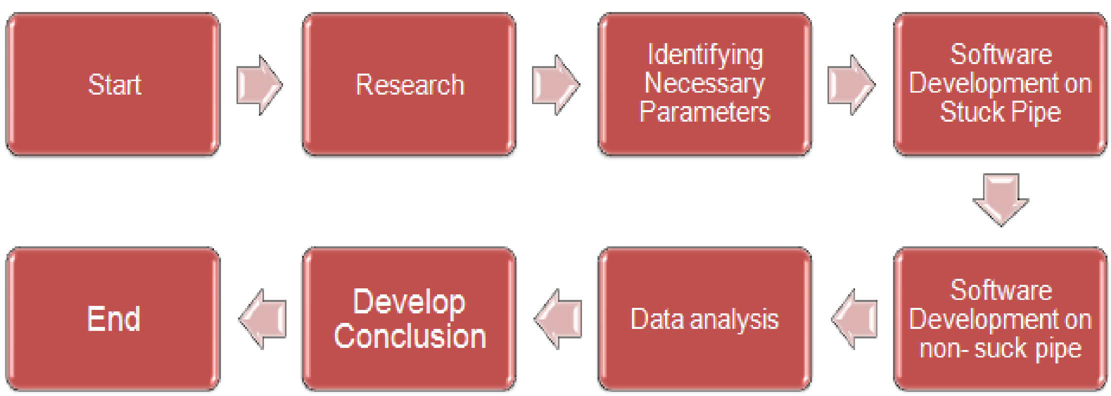

Figure 3.1. Project Flow Chart

I. ***Project Start***: In this phase, the project title had confirmed and then specify the problem statement work will be done.

II. ***Research***: After done the specifying problem statement, research on the theory and concept from any trusted sources will be made. Deeper understanding is very important to make sure the project follow all the basic theory.

III. ***Identifying Necesarry Parameters***: Such as in-situ stresses, pore pressure, type of formation, mud weight window and well tracjectory.

IV. ***Software development on stuck pipe***: the software development will be using landmark software the Halliburton software. The type of software will be use either *WELLPLAN* or *DRILLWORK*

V. ***Software development on non-stuck pipe***: : the software development will be using landmark software the Halliburton software. The type of software will be use either *WELLPLAN* or *DRILLWORK* this is to see the effect of geomechanics study will help encountered or mitigate the stuck pipe problem.

VI. ***Data Analysis***: Data taken or execute by software during software development will be analysed to see the difference between using geomechanics study or not.

VII. ***Develop Conclusion***: This is the crucial part in this project where author need to develop the conclusion from the project execute.

VIII. ***End of Project***: In this phase, the report will be submitted

3.2 RESEARCH METHODOLOGY & PROJECT ACTIVITIES

Figure 3.2 below shows the overview of research methodology and description of each step in project activities.

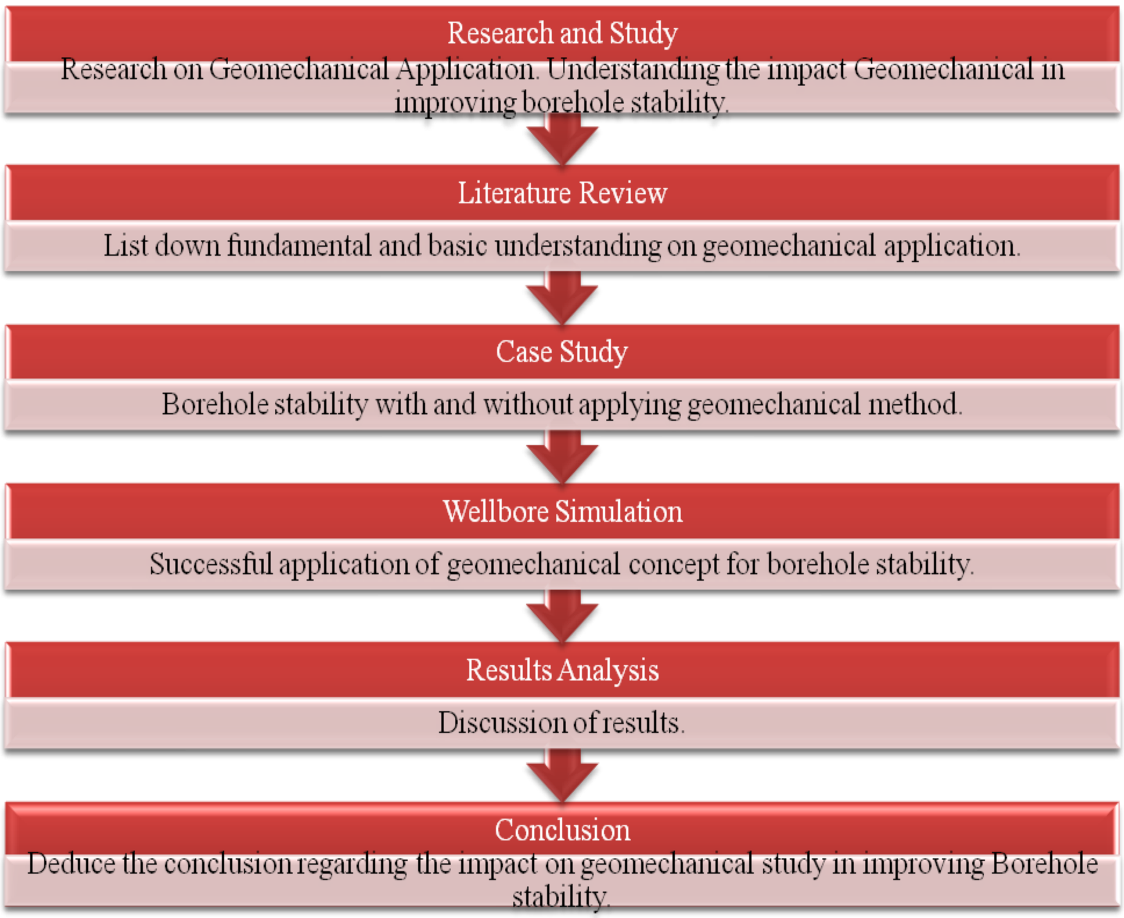

Figure 3.2. Research Methodology Project Activities Flow

3.3 GANTT CHART

Table 3.1. Gantt Chart FYP

No.	Task	JANUARY				FEBUARY				MARCH				APRIL			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1.0	**Application of Geomechanical to Borehole Stability Study**																
	1.1 Outsource Reading Materials																
	1.2 Compose Project Proposal																
	1.3 Submit Project Proposal to Supervisors																
2.0	**Project Preliminary**																
	2.1 Supervisors Consultation																
	2.2 Conduct research on Pipe Stuck																
	2.3 Background study of the Geomechanical Application																
	2.4 Identifying Necessary Parameters to Achieve Objectives																*1
		MAY				JUNE				JULY				AUGUST			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
3.0	**Project Analysis**																
	3.1 Data Collection from the Experiment																
	3.2 Data Analysis																
	3.3 Supervisors Consultations																
4.0	**Project Finalization**																
	4.1 Develop Conclusion and Recommendations																
	4.2 Final Report Preparation														*2		
	4.3 Endorsement from Supervisors																

- Milestone 1 – Parameter Identification
- Milestone 2 – Preparation of Project Dissertation

CHAPTER 4: RESULT AND DISCUSSION

4.1 ROCK MECHANICAL PROPERTIES

Dynamic elastic properties equation

$$E_{dyn} = \frac{9 \times G_{dyn} \times K_{dyn}}{G_{dyn} + 3 \times K_{dyn}} \qquad \text{- Equation (1)}$$

Use to compute rock strength and in-situ stresses. Dynamic elastic properties only can be calculated if compressional and shear slow nesses, and density are available.

4.2 IN SITU STRESSES

In situ stress is an important component in geomechanic modeling. Any geomechanical modeling will needs the strength properties of rock and in situ stress magnitude as input. The poisson's ratio and Young's modulus is then calculated by using sonic logs, this both poisson's ratio and Young's modulus will be calibrated by using static core measurements.

The overburden stresses is computed by integrating bulk density logs. A vertical stress is given below where (pb) is the bulk density:

$$\sigma_v = \int_0^z P_b\,(z) \times g \times dz \qquad \text{- Equation (2)}$$

The in situ stress regime is a transition from normal to thrust type with the maximum horizontal stresses which slightly higher than the vertical stress.

Minimum horizontal stress

$$\sigma_h = \frac{v}{1-v}\sigma_v + \frac{1-2v}{1-v}\alpha P_p + \frac{E}{1-v^2}\varepsilon_x + \frac{vE}{1-v^2}\varepsilon_y \qquad \text{- Equation (3)}$$

Maximum horizontal stress

$$\sigma_H = \frac{v}{1-v}\sigma_v + \frac{1-2v}{1-v}\alpha P_p + \frac{E}{1-v^2}\varepsilon_y + \frac{vE}{1-v^2}\varepsilon_x \qquad \text{- Equation (4)}$$

Maximum Horizontal stress will be higher than vertical stress and vertical stress will be higher than minimum horizontal stress:

$$\sigma_H \geq \sigma_v > \sigma_h \qquad \text{- Equation (5)}$$

4.3 DATA PREPARATION FROM RESEARCH PAPER

4.3.1 Summary of LOT Tests

Table 4.1. Summary of LOT Tests

Depth (mTVD)	Deviation (deg.)	Leak Off Test (SG)
561	0	1.68
325	2	1.66
825	35	1.75
548	1.9	1.66

Leak Off Test data approximately estimate the magnitude of the minor horizontal stress. The major horizontal stress was estimated by matching the predicted wellbore failure with the drilling records and image data.

Since the overburden stress, pore pressure and minor horizontal stress were calibrated and constrained, there will be confidence in the major horizontal stress magnitude if the predicted borehole features matched those observed from image and caliper data. On, average the major horizontal stress was approximately 1.1 times of the minor horizontal stress.

4.3.2 Summary of ultrasonic wave velocities and dynamic moduli of Sa He Jie Shale

Table 4.2. Summary of Ultrasonic wave velocities and dynamic moduli of Sa He Jie Shale

Block	Wave Propagating Direction	Ultrasonic Velocity		Bulk Density (g/cm3)	Dynamic Young's Modulus (GPa)	Dynamic Poisson's Ratio	Static Young's Modulus (GPa)
		Compressional (m/s)	Shear (m/s)				
1	Perpendicular to bedding	2576.86	1578.00	2.32	13.86	0.20	2.34
	Parallel to bedding	3489.00	1757.00	2.32	19.05	0.33	3.93
2	Perpendicular to bedding	2651.98	1624.00	2.54	16.06	0.20	2.97
	Parallel to bedding	3671.00	1560.00	2.54	17.17	0.39	3.31

Two large caving blocks of Sa He Jie shale were made available for study. Deformation anisotropy was evaluated by measuring ultrasonic compressional and shear wave velocities parallel and perpendicular to the bedding planes at ambient condition.

The measured average unconfined compressive strength is approximately 90 MPa for the intact shale material and 47 MPa for shale bedding plane. The strength of intact Sa He Jie shale is obtained from the MEM constructed from the research paper.

Failure of intact shale and bedding planes was then evaluated by comparing the effective stress with the strengths if intact shale and bedding planes. In this way, the minimum mud weights to maintain the intact shale and bedding plane stable were determined.

By repeating the process for full range of well azimuths and inclinations, a contour plot of minimum mud weight to prevent borehole breakout can be obtained.

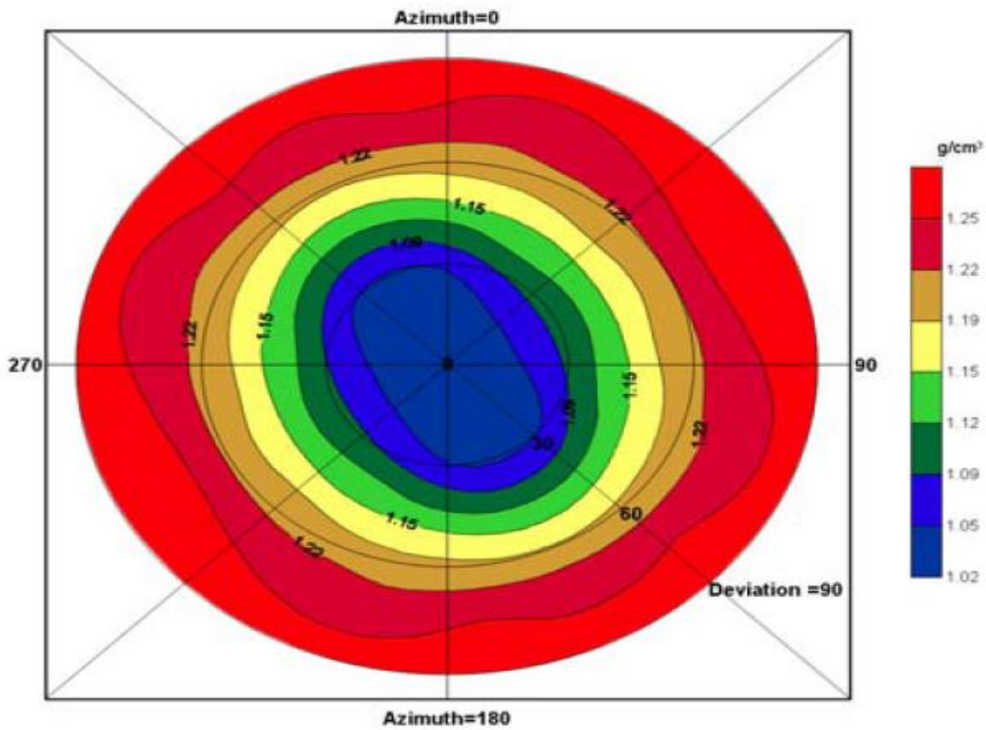

Figure 4.1. Contour plot of borehole failure mud weight

4.3.3 Summary of Planned and Recommended Mud Weights

Table 4.3. Summary of Planned and Recommended Mud Weights

Hole Size	Casing Depth (mMDRT)	Formation	Planned Mud Weight (SG)	Recommended Mud Weight (SG)
17 1/2" (47.4m ~ 1252m(	47.4-1252	Ping Yuan – Ming Hua Zheng	1.08 (1.05-1.10)	1.10
12 ¼"	1252-2400	Ming Hua Zheng – Guan Tao 1	1.14 (1.10-1.15)	1.14
	2400-3335	Guan Tao 1 – Sa He Jie	1.17 (1.15-1.18)	1.17
8 ½"	3335-4263	Sa He Jie	1.09 (1.10-1.18)	1.12

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

During the drilling, a lot of drilling operation can cause the stuck pipe problem. Geomechanics method has proven to be efficient in mitigating the borehole instability problem during the drilling operation. This project analyzes the study of geomechanics study in avoiding the stuck pipe problem in regards to borehole instability.

Based on case studies from this project the geomechanics approach solved the stuck pipe problem in regards to borehole instability. The borehole stability analysis which is one of geomechanics approach helps to minimize the borehole instability which will lead to avoiding stuck pipe occurrence during the drilling operation.

This project summarizes the geomechanics data that needed in order to undergo the simulation of borehole stability analysis for stuck pipe and non stuck pipe. This study is needed to ensure that drilling operation can be undergo by mitigate the stuck pipe problem by using the geomechanics approach.

5.2 RECOMMENDATIONS

Borehole instability problem had been faced over decades in drilling industries. According to this research, application of geomechanic signicantly had shown the positive impact towards solving borehole instability. In this research, simulation for borehole stability analysis for stuck pipe and non-stuck pipe had been not carried forward. This work will be future scope of the present work.

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